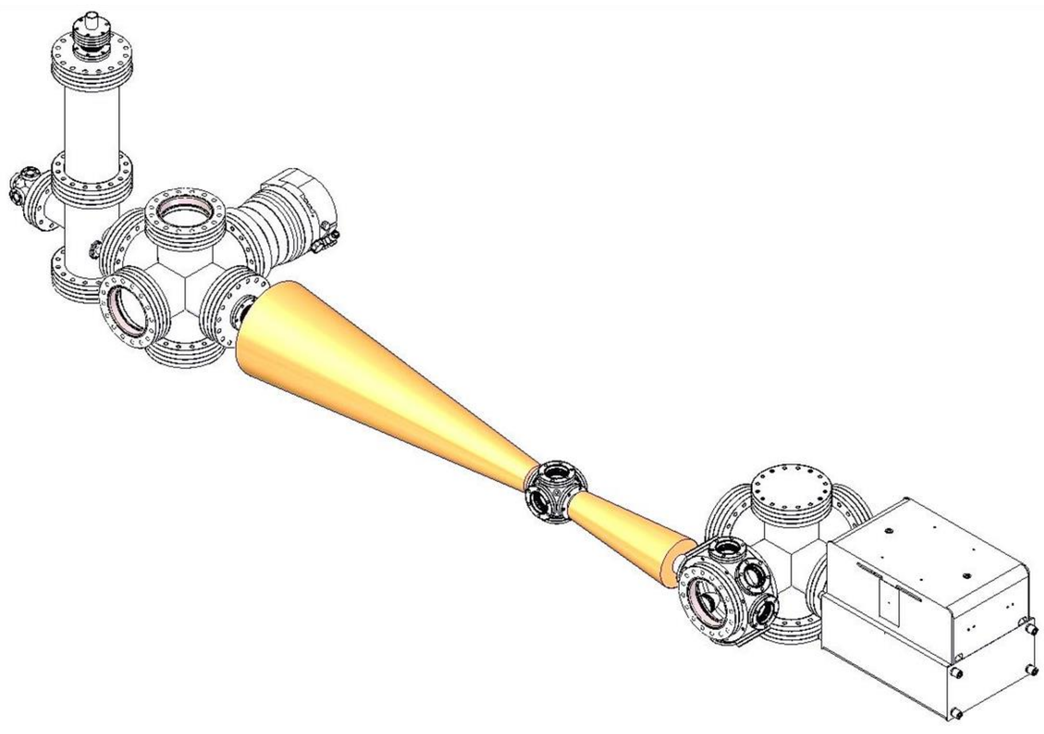
Progress towards an argon magneto-optical trap for weak interaction studies at ULg



Dr. Rohan Glover
University of Liege

Prof. Thierry Bastin
University of Liege

Motivation

- The normalization of states requires the CKM matrix to be unitary

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

- Unitarity test provides limits on new physics such as:
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Superallowed Fermi decays	K-decays	$\|V_{ub}\|$ negligibly small
$\|V_{ud}\| = 0.97425(22)$	$\|V_{us}\| = 0.2252(9)$	$\|V_{ub}\| \approx 0$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.99990(60)^{1}$$

[1]Severijns *et al*, Physica Scripta, **152T** 014018 (2013)

T=1/2 mirror β transitions

Recently pointed out that the T=1/2 mirror β transitions could also be used to test $|V_{ud}|$

PRL **102,** 142302 (2009) PHYSICAL REVIEW LETTERS week ending 10 APRIL 2009

Test of the Conserved Vector Current Hypothesis in $T = 1/2$ Mirror Transitions and New Determination of $|V_{ud}|$

O. Naviliat-Cuncic[1] and N. Severijns[2]

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[2]*Instituut voor Kern- en Stralingsfysica, Katholieke Universiteit Leuven, B-3001 Leuven, Belgium*

(Received 23 January 2009; published 8 April 2009)

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$$\mathcal{F}t_0 = ft(1+\delta'_R)(1+\delta_{NS}-\delta_C)\left[1+\left(\frac{f_A}{f_V}\right)\rho^2\right] = \frac{K}{G_F^2 V_{ud}^2 (1+\Delta_R^V)}$$

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Right hand side:

$K/(\hbar c)^6 = 2\pi^3 \hbar \ln 2/(m_e c^2)^5$

$G_F/(\hbar c)^3$ - is the Fermi coupling constant

$\Delta_R^V = (2.361 \pm 0.0038)\%$ - is the radiative correction

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T=1/2 mirror β transitions

Left hand side:

f - is the statistical rate function

t - is the partial half-life of the transition

δ'_R , δ_{NS} and δ_C - are transition dependent corrections

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ρ – is the Fermi/Gamow-Teller mixing ratio

$$a_{SM} = \frac{1-\rho^2/3}{1+\rho^2}$$

$$A_{SM} = \frac{\mp\frac{1}{J+1}\rho^2 - 2\sqrt{\frac{J}{J+1}}\rho}{1+\rho^2}$$

Potential of ^{35}Ar

Phys. Scr. **T152** (2013) 014018 N Severijns and O Naviliat-Cuncic

Table 1. Precision on $|V_{ud}|$ obtained from the individual mirror nuclei when the β–ν correlation coefficient a (columns 2–4), respectively the β-asymmetry parameter A (columns 5–7) are determined with a relative precision of 0.5%. Columns 2 and 5 list the precision on $|V_{ud}|$ when the actual $\mathcal{F}t$-values for the mirror transitions [40] are used. Columns 3 and 6 list the precision on $|V_{ud}|$ when the $\mathcal{F}t$-value would be sufficiently well known such that it would not contribute to the error on $|V_{ud}|$ anymore. The factor by which the $\mathcal{F}t$-values have to be improved to reach this situation are listed in columns 4 and 7, respectively. For ^{19}Ne the new value $\mathcal{F}t = 1721.5(17)$ s was used which includes, apart from the data listed in [40], also the new mass excess from [54] and the new half-life from [51].

	a			A		
Parent nucleus	ΔV_{ud}	$(\Delta V_{ud})^{\text{limit}}$	Factor $\Delta\mathcal{F}t$	ΔV_{ud}	$(\Delta V_{ud})^{\text{limit}}$	Factor $\Delta\mathcal{F}t$
^{3}H	0.0011	0.0010	2.1	0.0011	0.0009	2.3
^{11}C	0.0025	0.0016	4.0	0.0207	0.0207	0.3
^{13}N	0.0017	0.0017	1.0	0.0123	0.0123	0.1
^{15}O	0.0020	0.0016	2.4	0.0023	0.0020	1.9
^{17}F	0.0019	0.0013	3.1	0.0341	0.0341	0.1
^{19}Ne	0.0011	0.0010	1.5	0.0011	0.0011	1.5
^{21}Na	0.0022	0.0017	2.7	0.0036	0.0034	1.3
^{23}Mg	0.0025	0.0018	3.1	0.0034	0.0030	1.9
^{25}Al	0.0019	0.0018	1.7	0.0056	0.0056	0.5
^{27}Si	0.0029	0.0018	4.1	0.0068	0.0066	1.1
^{29}P	0.0026	0.0018	3.4	0.0024	0.0014	4.3
^{31}S	0.0038	0.0018	5.9	0.0068	0.0061	1.8
^{33}Cl	0.0021	0.0018	2.0	0.0013	0.0006	6.0
^{35}Ar	0.0019	0.0018	1.1	0.0007	0.0004	4.8
^{37}K	0.0034	0.0017	5.8	0.0050	0.0041	2.3
^{39}Ca	0.0024	0.0016	3.5	0.0032	0.0027	2.2
^{41}Sc	0.0029	0.0022	2.7	0.0299	0.0299	0.2
^{43}Ti	0.0076	0.0018	13.2	0.0167	0.0151	1.6
^{45}V	0.0112	0.0020	17.7	0.0115	0.0032	11.2

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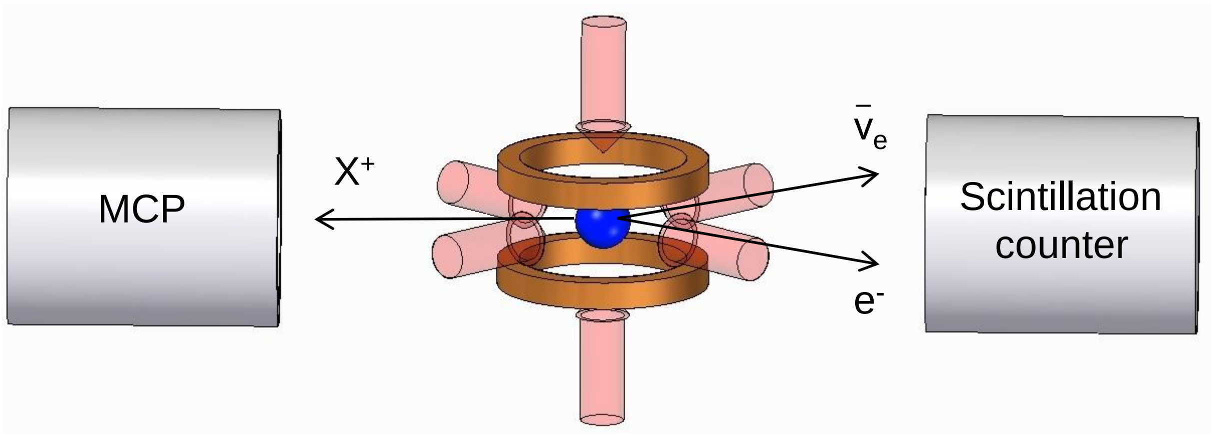
β-decay correlations using a MOT



[1]Gorelov *et al*, PRL, **94** 142501 (2005)

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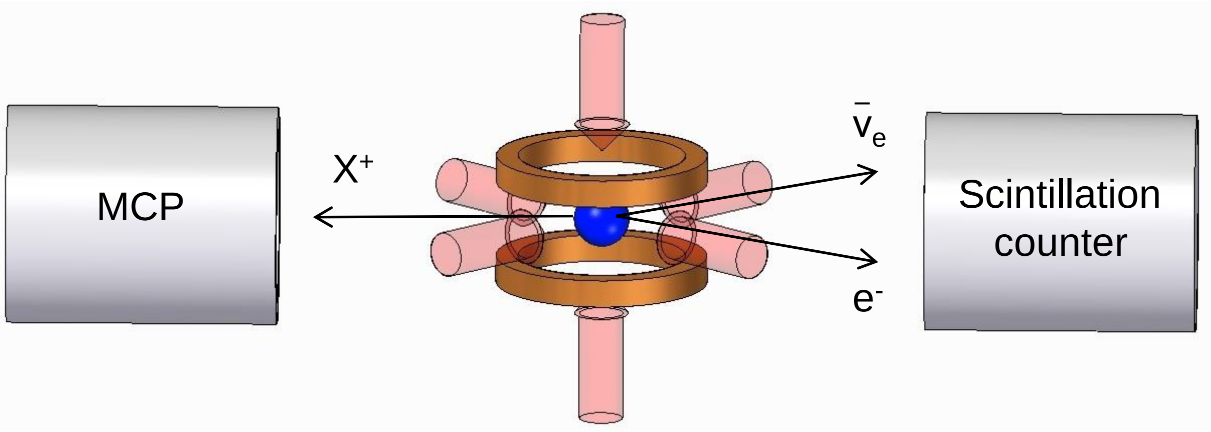

✓ MOT very accurate method for β-decay measurements

e.g. $a_{\beta\nu} = 0.9981(30)(37)$ in ^{38m}K decay[1]

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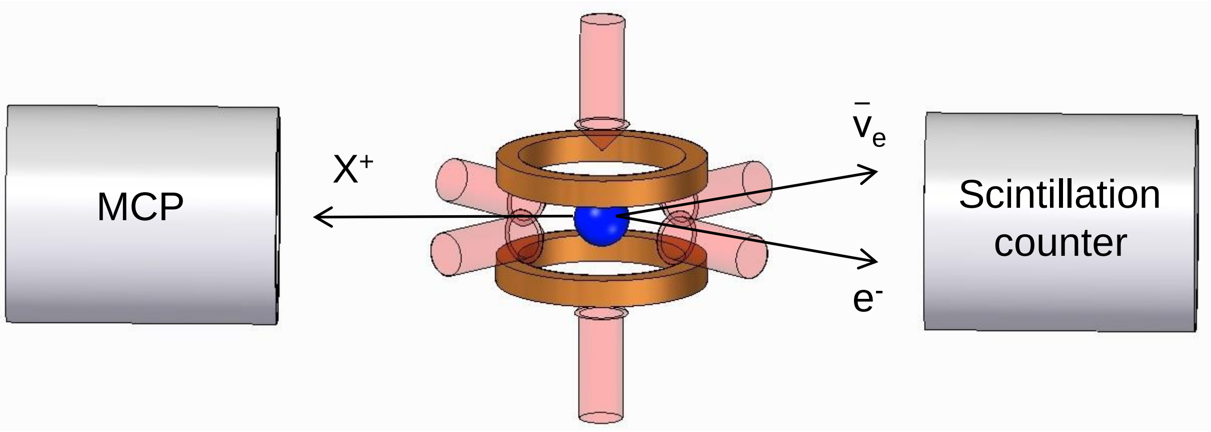

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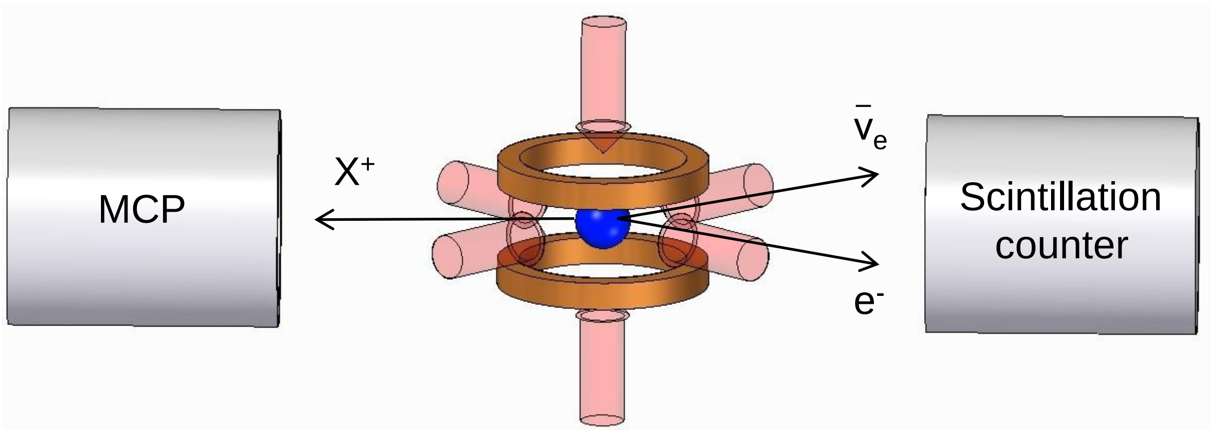

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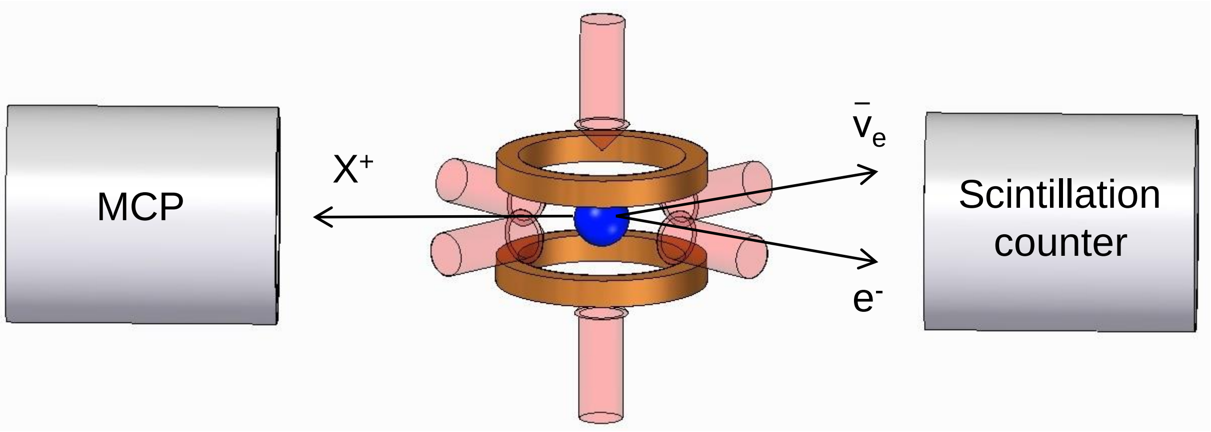

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✓ Extremely high nuclear polarizations are possible

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β decay correlation coefficients

General formula for the angular distribution of the β-decay:

$$\frac{d^5\Gamma_{angular}}{dE_e d\Omega_e d\Omega_\nu} \propto \left\{ 1 + a_{\beta\nu}\frac{\vec{p}_e \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + P\hat{i}\left[A_\beta \frac{\vec{p}_e}{E_e} + B_\nu \frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu} \right] \right.$$

$$\left. + c\left[\frac{\vec{p}_e \cdot \vec{p}_\nu}{3E_e E_\nu} - \frac{(\vec{p}_e \cdot \hat{i})(\vec{p}_\nu \cdot \hat{i})}{E_e E_\nu} \right] \left[\frac{I(I+1) - 3\left\langle (\vec{I} \cdot \hat{i})^2 \right\rangle}{I(2I \mp 1)} \right] \right.$$

Where (E_l, p_l) are the four-momenta of the leptons, $P = (|\vec{I}|/I)$ is the nuclear polarization of the parent nucleus along, $\vec{\imath}$.

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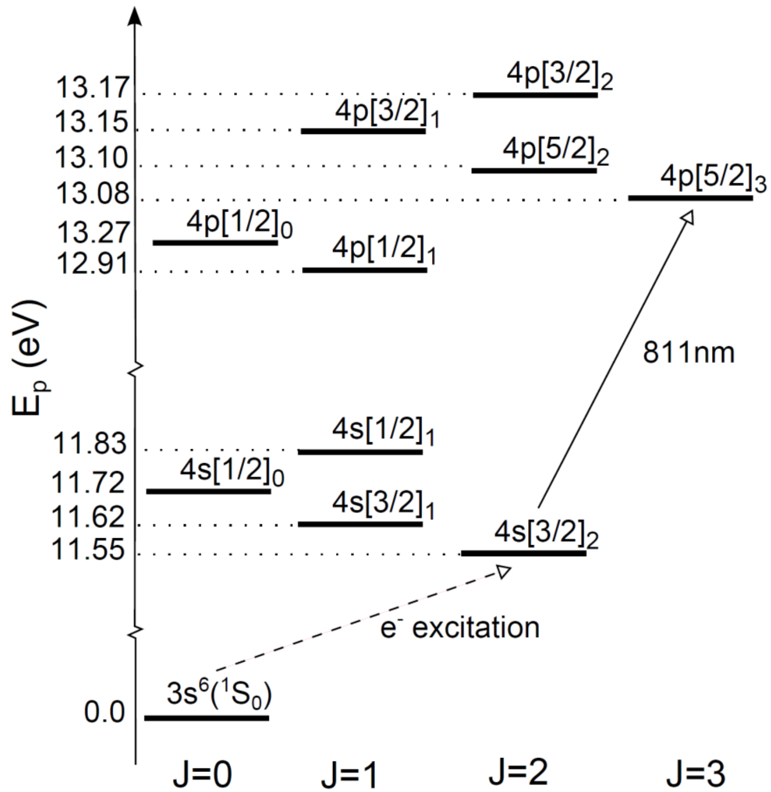
Measurement of A_β requires knowledge of the nuclear polarisation P

Atomic transitions - ^{35}Ar I=3/2



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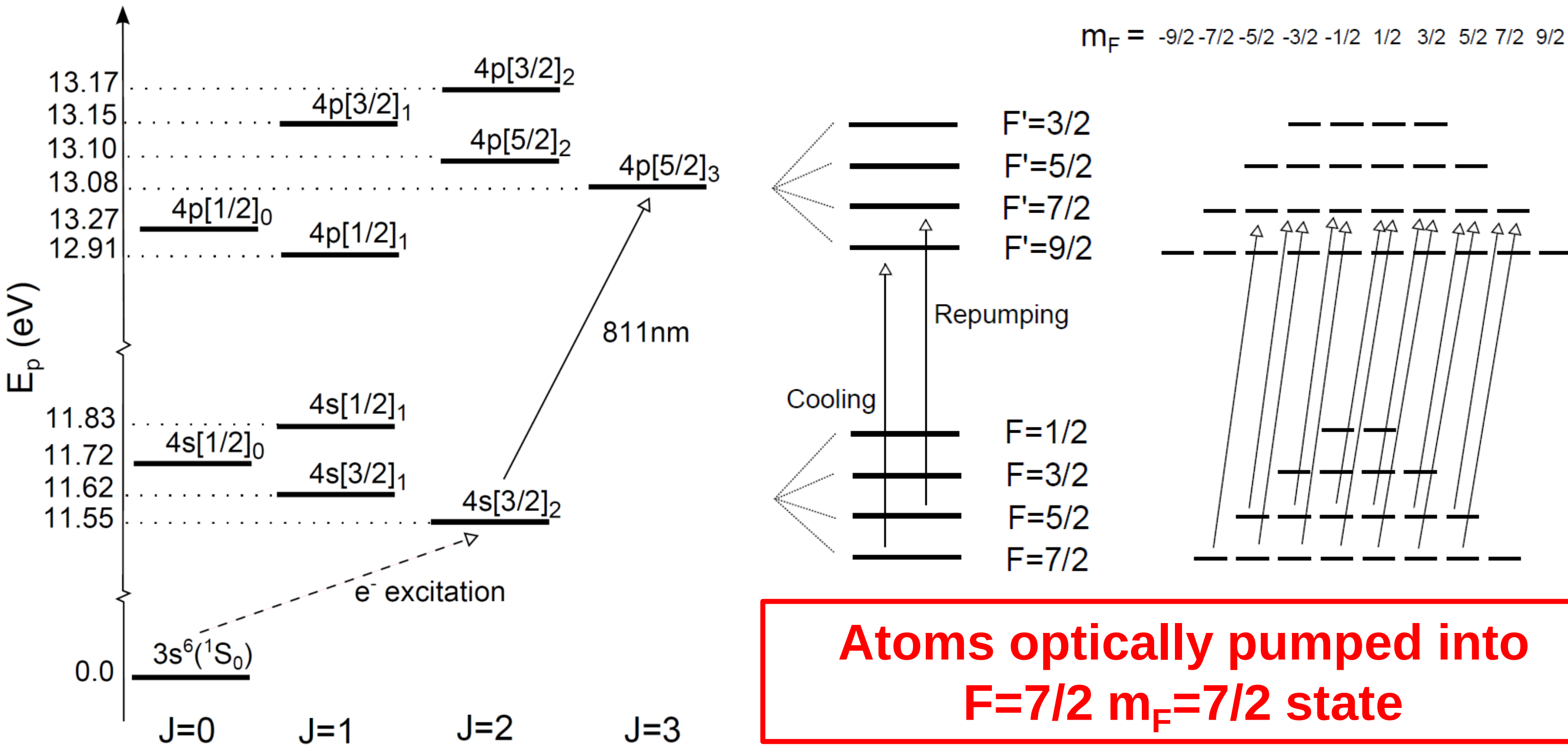

Atoms optically pumped into F=7/2 m_F=7/2 state

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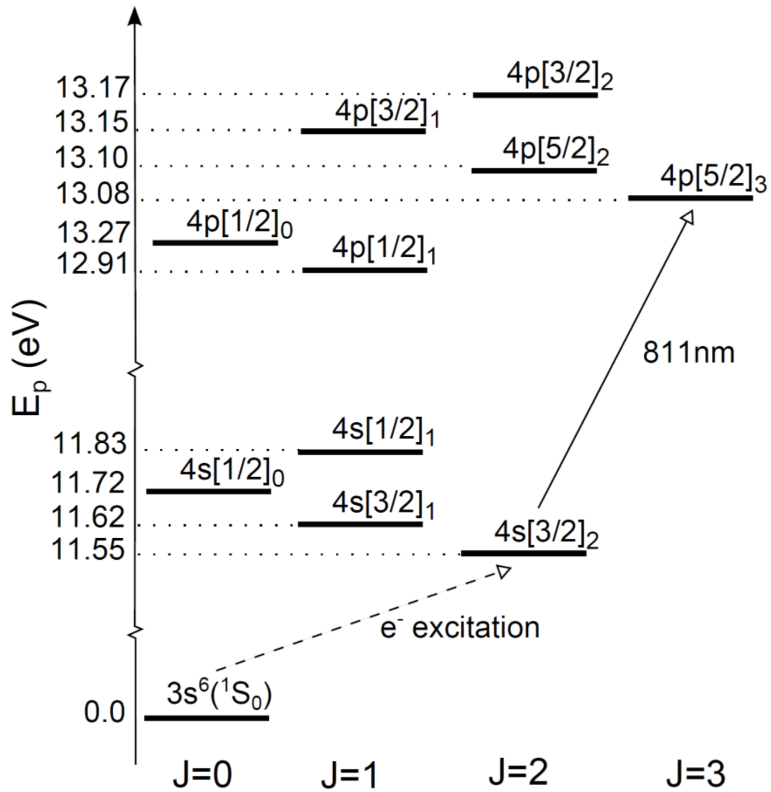

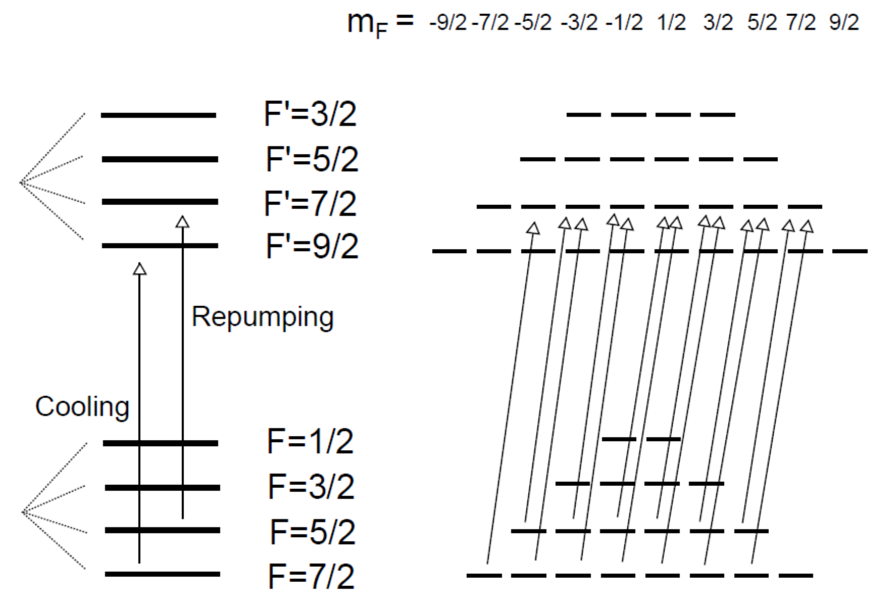

Atoms optically pumped into F=7/2 m_F=7/2 state

Spin polarization in a K MOT : 96.5(8) %[1]

Spin polarization in a Rb optical dipole trap : 99.2(2) % [2]

[1]Melconian *et al*, Phys Lett B, 649 p370 (2007) [2]Fang *et al*, Phys Rev A, 83 013416 (2011)

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Preliminary experiments with ^{40}Ar

Develop trapping techniques

- » development of laser systems
- » metastable argon source
- » transverse laser cooling
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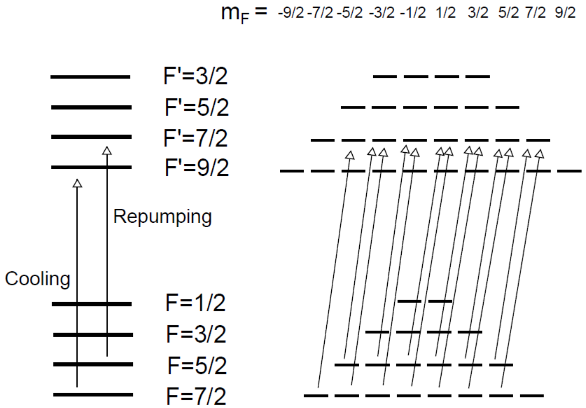
Develop polarisation techniques

- » optical pumping
- » dipole force trap
  - measurement of trap loss rates
- » develop measurement techniques



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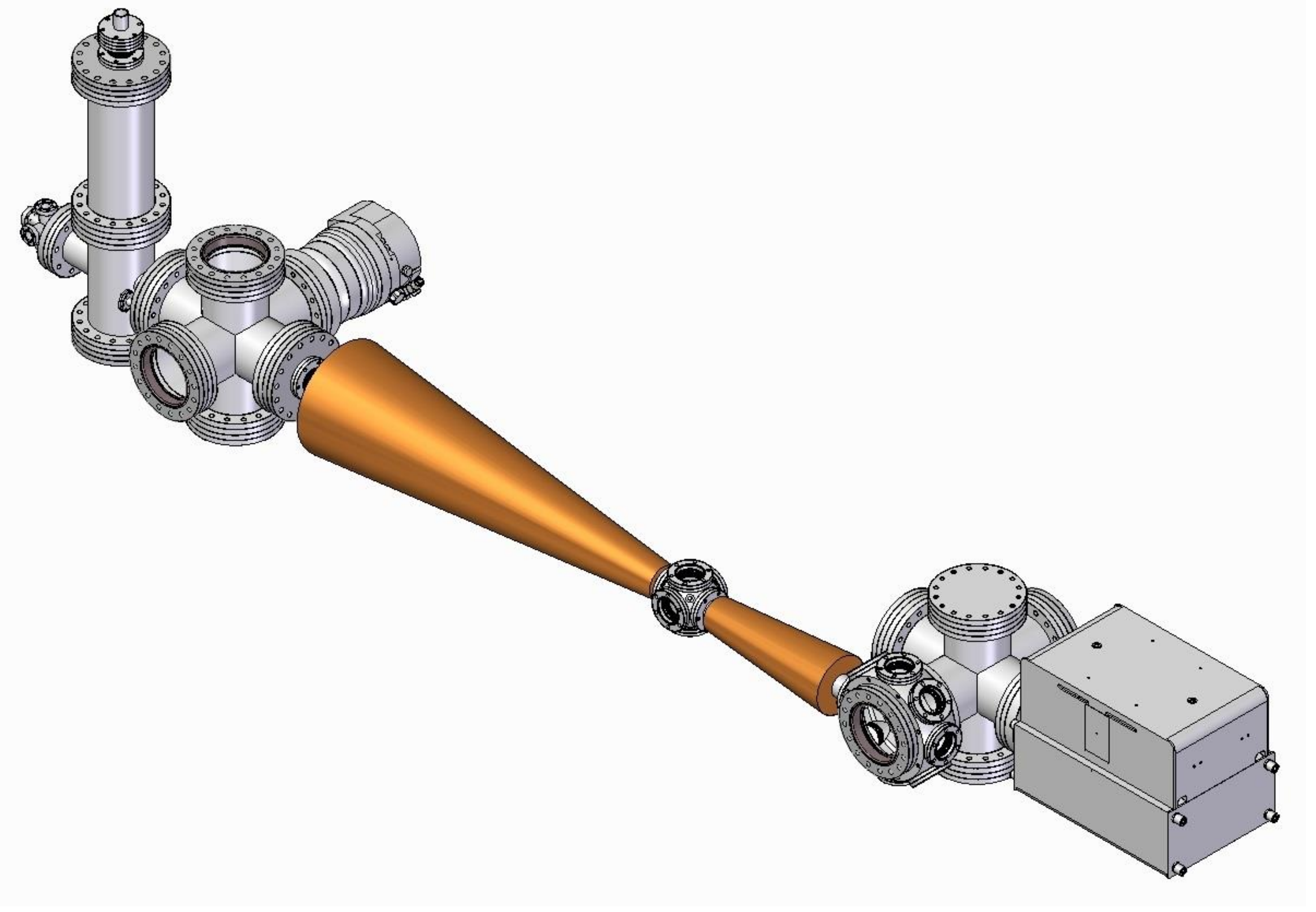
Apparatus schematic



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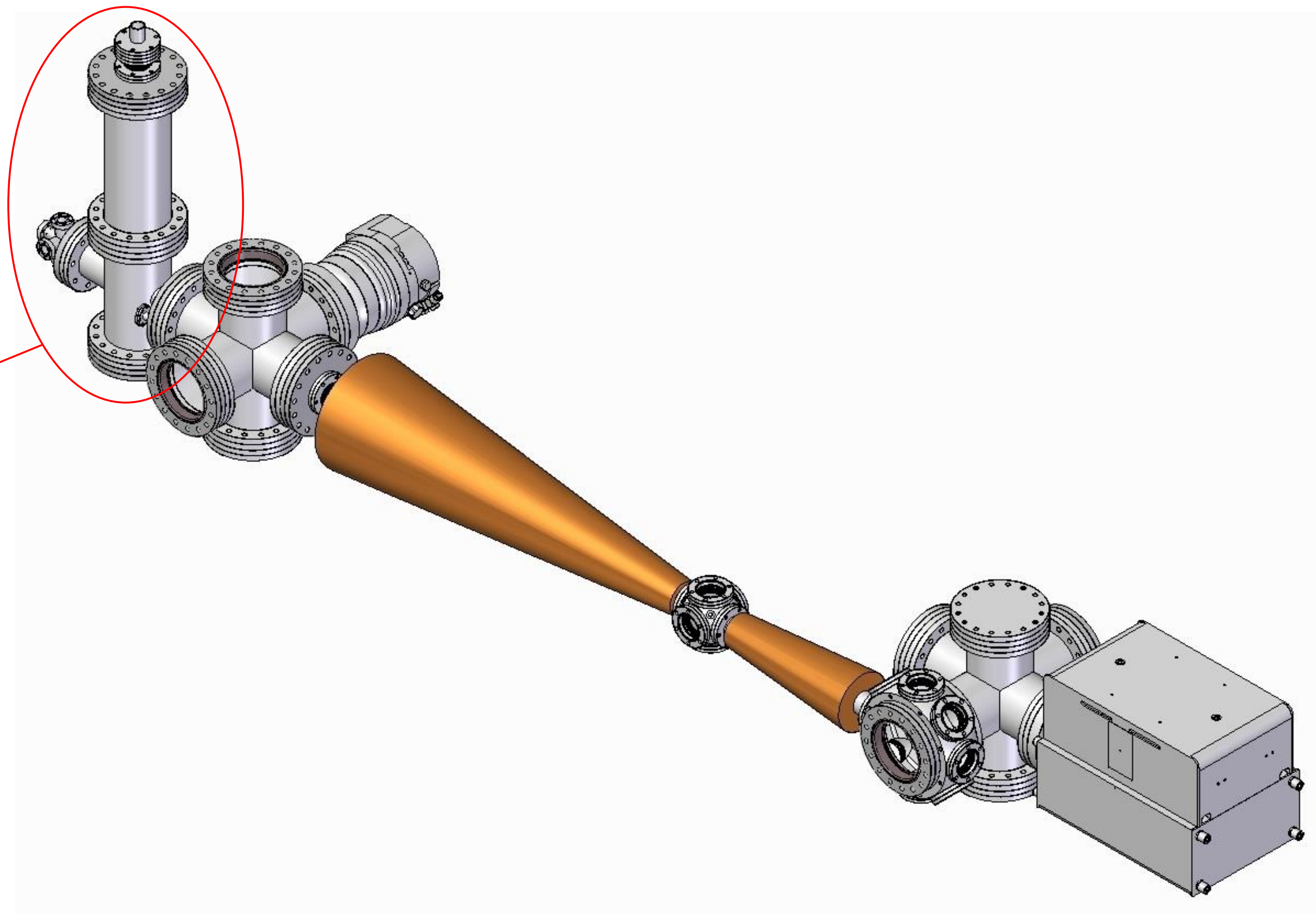
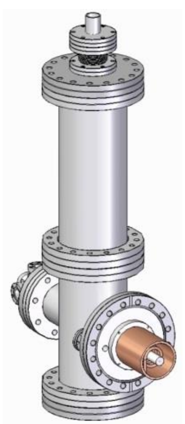


Metastable source



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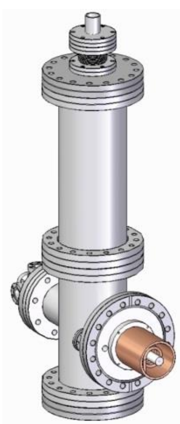
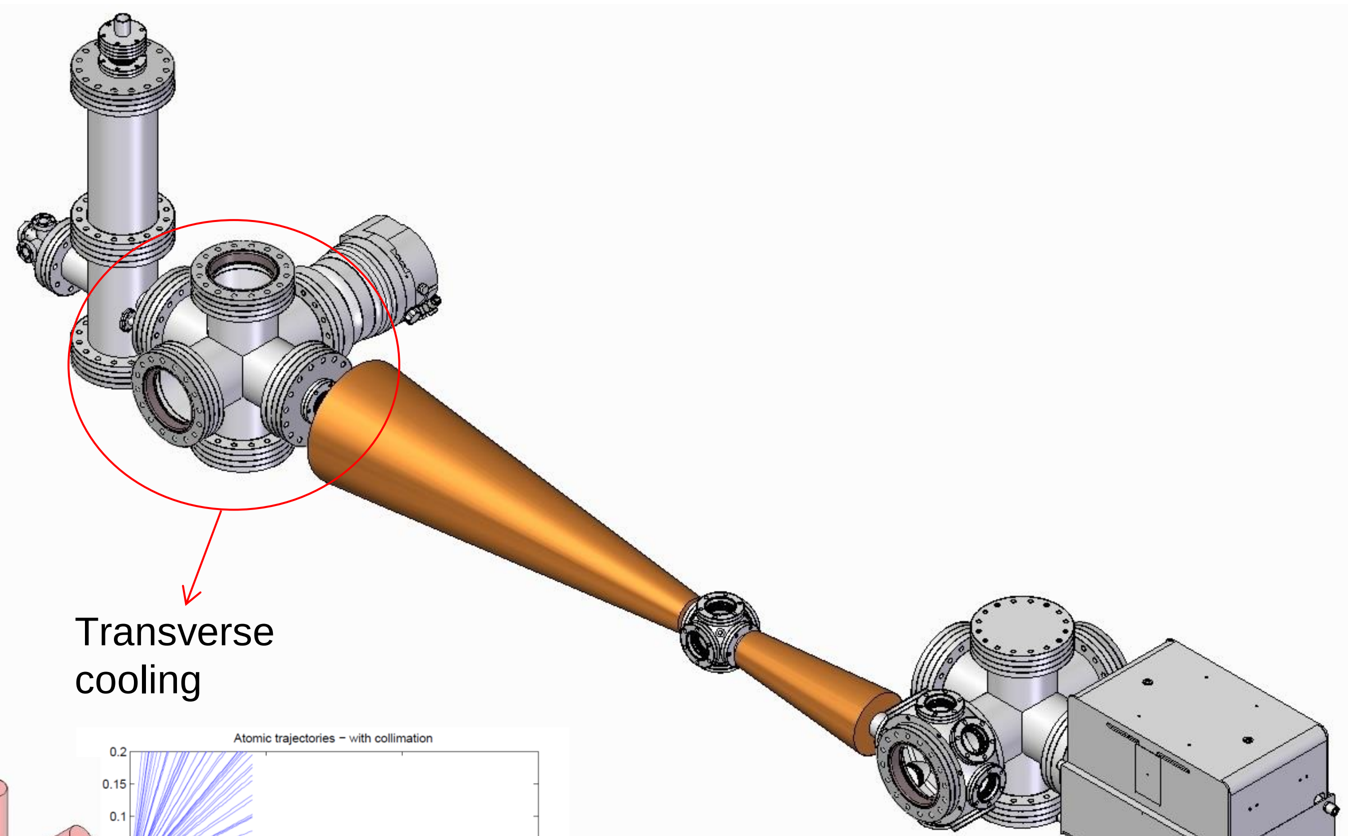
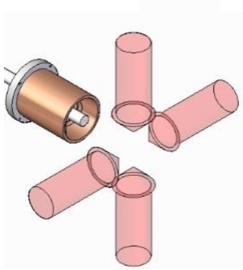
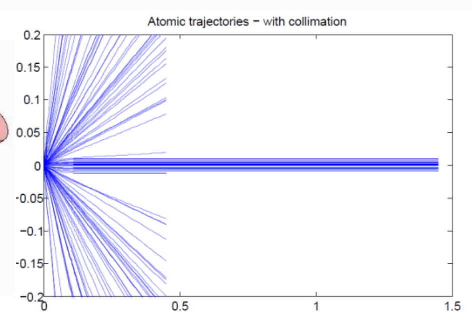




Transverse cooling





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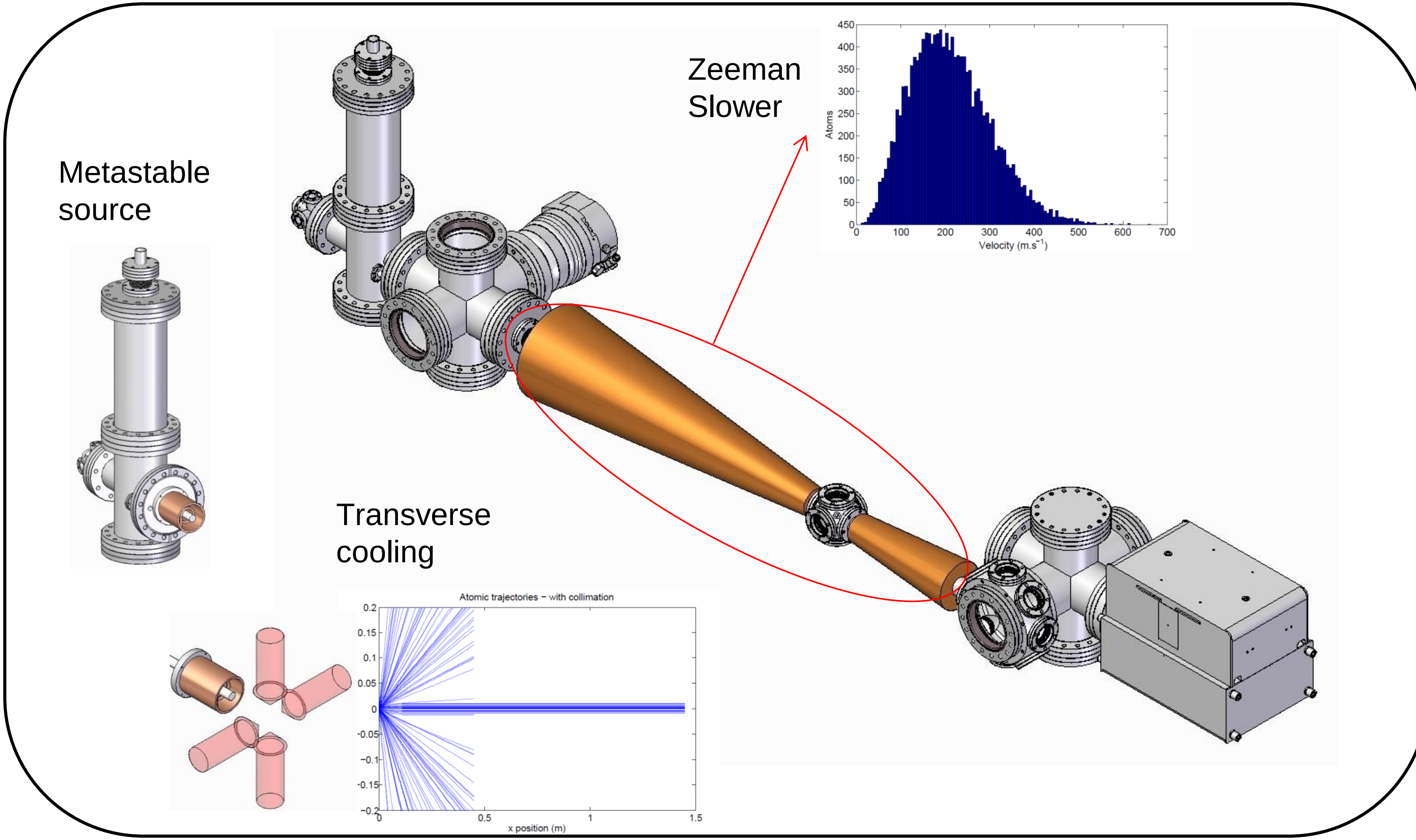

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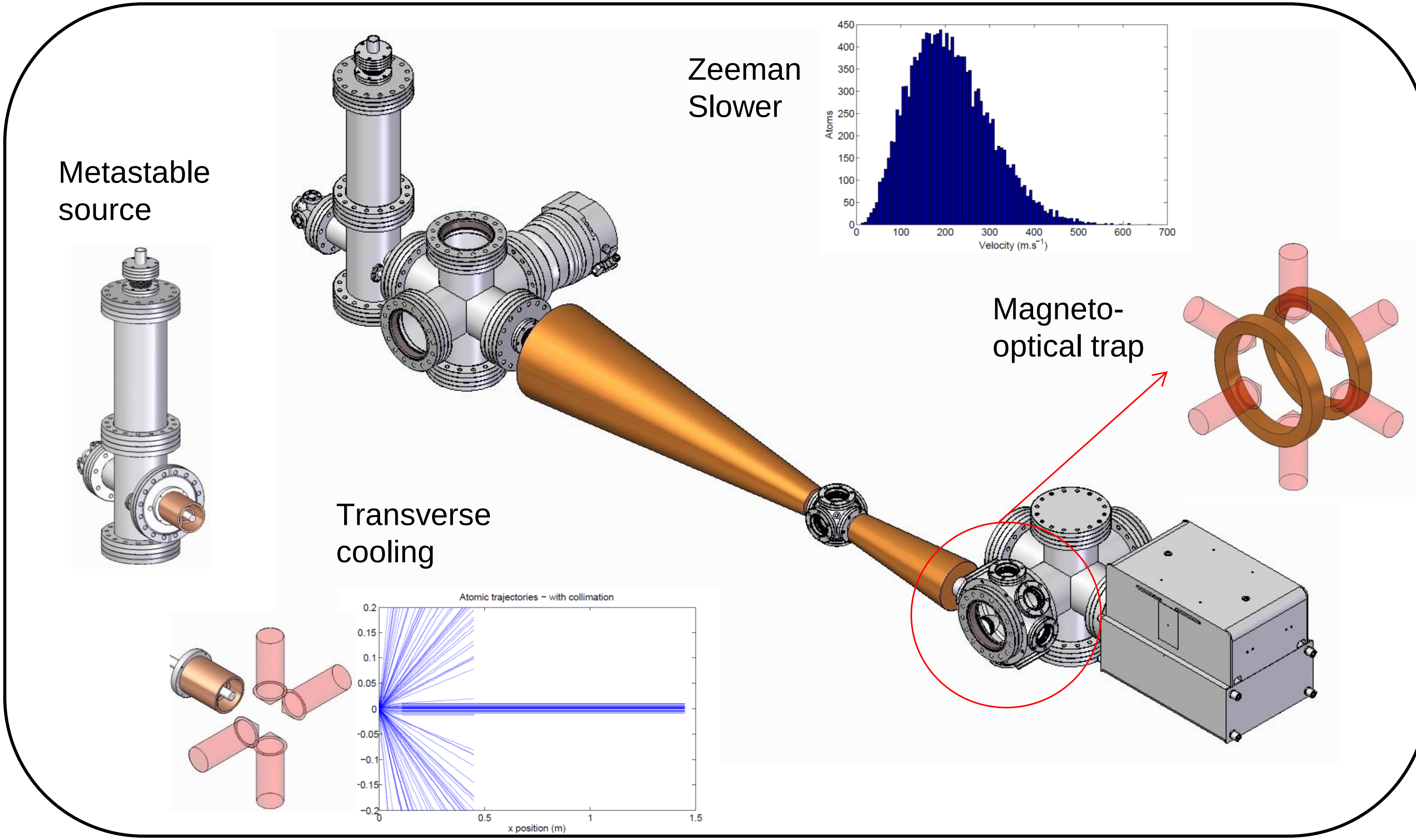

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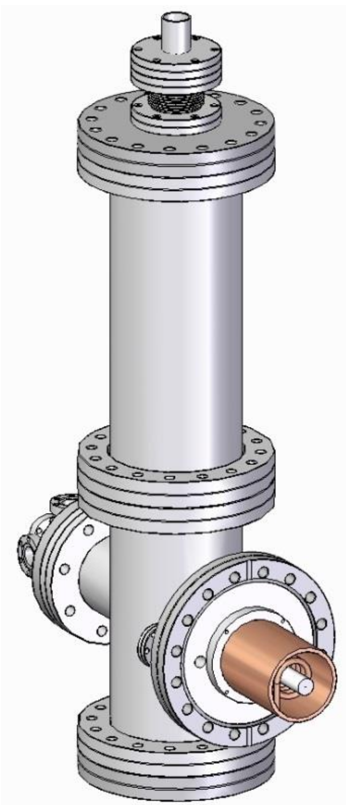
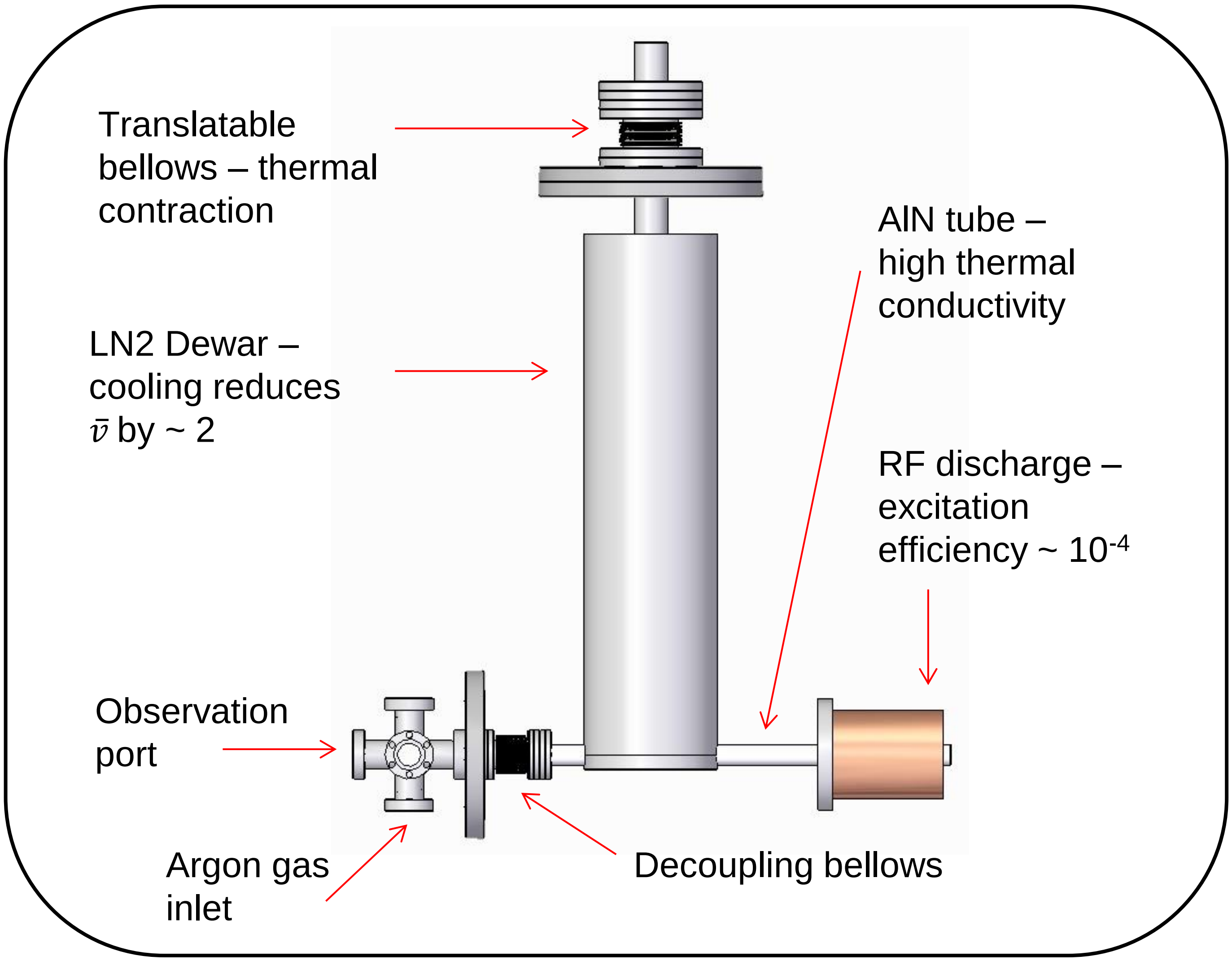
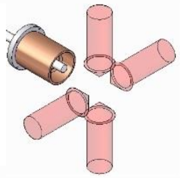
Metastable source design





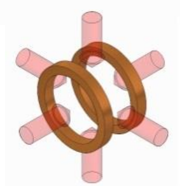
Expected trap efficiency

RF Discharge 10^{-4}



Transverse Cooling 10^{-2}

Zeeman Slower > 0.5



MOT ~ 1

Total <u>5×10^{-7}</u>

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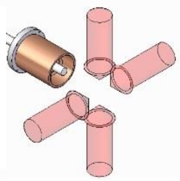

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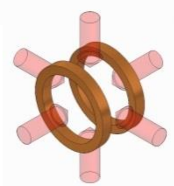

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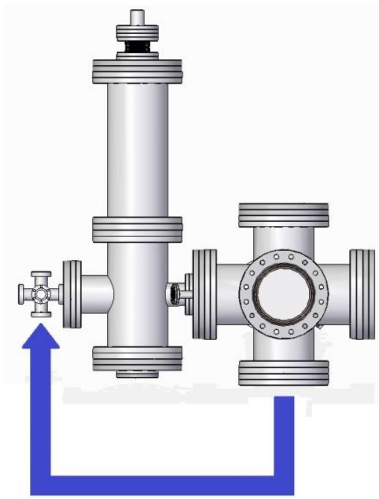
Gas re-circulation



approx. factor 10 improvement

best expected ~10^{-5}

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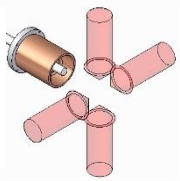

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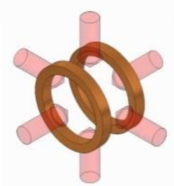

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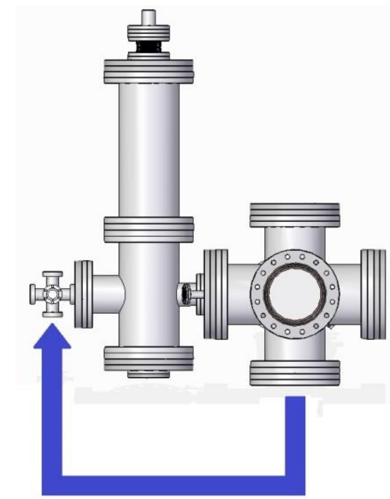

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Currently a limitation – requires further investigation!

Current status

- June - Optical table delivered
- Actively stabilized

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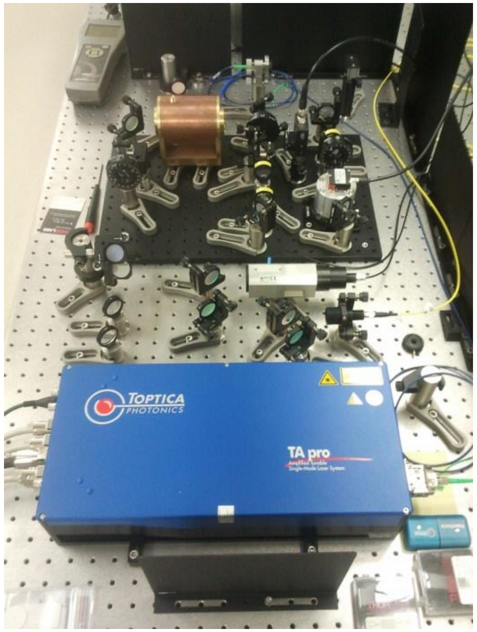
  - October - Laser systems arrives

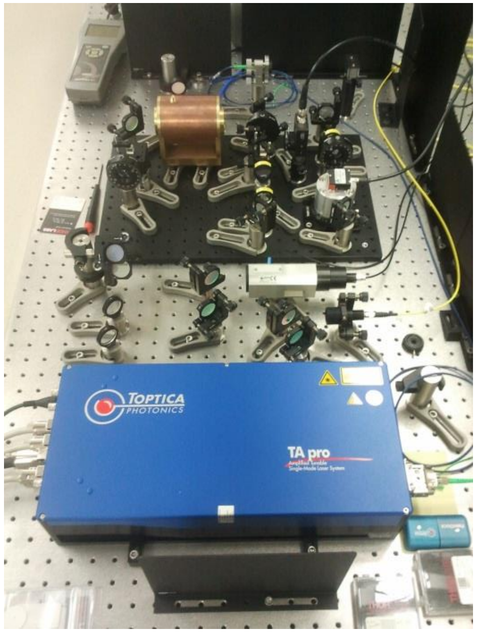


- 2 Watt of power @ 811.74 nm
- 1.1 Watt usable after fiber
- Linewidth 150 kHz

  ~ 10^{-7} nm

Current status

- June - Optical table delivered
- Actively stabilized

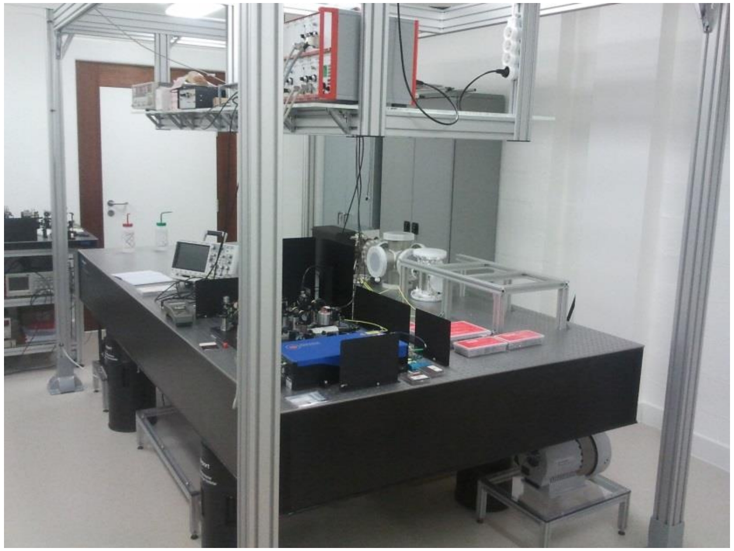


- October - Laser systems arrives

- 2 Watt of power @ 811.74 nm
- 1.1 Watt usable after fiber
- Linewidth 150 kHz

  ~ 10^{-7} nm

- November -
- Developing spectroscopy
- Next step - installation of vacuum apparatus



Summary

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  - » developing locking systems inc. spectroscopy of ^{40}Ar
- Metastable source has been designed and is being installed
- Performing modeling of atomic beam inc. transverse cooling
- Need to further develop techniques for either :
  - » improving efficiency of excitation to metastable state, or
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Thank you